



**Software Engineering Department**

**Braude College of Engineering**

**Final Project – Phase A (61998)**

## **Automated System for University Exam Scheduling**

**Project Code: 26-1-D-12**

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<https://github.com/KarynA19/Exam-Optimizer.git>

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# **Abstract**

The final examination scheduling process in academic departments is an extremely complex logistical task, demanding simultaneous compliance with a wide array of conflicting constraints derived from faculty availability, religious and academic calendar restrictions, classroom capacity, and the mandatory institutional rules regarding student examination load. Manually managing this process consumes valuable time resources, increases the risk of scheduling errors (such as overlaps or violations of holy day restrictions), and often results in sub-optimal timetables for both lecturers and students.

This project presents the development of a Computerized Examination Scheduling System, designed to automate this process for the Administrative Assistant to the Head of the Software Engineering Department, while ensuring full adherence to the college's policies and the specific demands of the department. The system utilizes optimization algorithms to generate a comprehensive schedule by implementing a multi-layered constraint model.

The model includes specific consideration for the following factors: distinction between regular faculty members and external lecturers (where only faculty constraints are considered); precise calendar restrictions (holidays, fast days, and fixed dates for Moed A and Moed B periods); mandatory student load rules (up to 3 weekly exams per student); handling of cross-departmental exams (held simultaneously); lecturer constraints (no two exams for the same lecturer in the same week).

The final system offers the user an initial automated scheduling along with the capability for a Re-shuffle based on secondary parameters, providing a flexible, accurate, and immediate solution to the scheduling problem.

## **1. Introduction**

### **1.1 General Background**

Academic institutions, and especially technological colleges with large departments such as the Software Engineering Department, routinely face a complex logistical task: scheduling final semester examinations (Moed A and Moed B periods). This process is not a simple matter of filling days and hours, but rather a multi-variable optimization problem that requires meticulous consideration of the needs and constraints of numerous factors: the academic faculty, the recommended course-taking route and the institutional calendar.

Examination timetables must comply with a long list of "Hard Constraints" whose violation is impossible. These constraints include, among others, religious regulations (fast days, holidays), student load rules (up to 3 weekly exams per student), faculty availability (regular permanent faculty members only), and mandatory fixed times for cross-departmental exams

## 1.2 The Need for an Automated System

Currently, the scheduling process is performed manually by the department's Administrative Assistant. This process is susceptible to multiple failures:

1. Time and Resources: The process consumes significant working time and requires repeated checks to locate clashes or constraint violations.
2. Risk of Errors: The complexity of the requirements, especially the distinction between permanent faculty and external lecturers, or the consideration of multi-faith fast days increases the risk of scheduling errors that could disrupt the academic order.
3. Lack of Optimality: Manual scheduling often leads to "achievable" solutions that are not optimal in terms of distributing the load on students.

There is a vital need for an automated system that will simplify the complex logistical task, ensure full compliance with all constraints, and provide the Administrative Assistant with a fast and reliable tool for generating the timetable.

## 1.3 Project Goal

The goal of this final project is to design and develop a Computerized Examination Scheduling System for the Software Engineering Department. The system will be based on an optimization model capable of weighing all the Hard Constraints collected from the Department Head's office, including:

- Constraints related to faculty (ranks, type of position).
- Calendar constraints (holidays, fast days, start and end of the semester, duration of Moed A and B).
- Operational constraints (cross-departmental exams).
- Mandatory student load limitations.

The final system will offer an initial automated scheduling solution and allow for further changes and re-shuffles based on secondary parameters, while maintaining full compliance with all rules. The system will streamline the workflow, reduce errors, and free up valuable administrative time.

## 2. Literature Review

The University Examination Timetabling Problem (UETP) is a classic NP-hard combinatorial optimization challenge that involves assigning examinations to limited time slots and rooms while satisfying a complex set of constraints. These constraints are categorized into strict logistical rules (Hard Constraints) that determine feasibility, and flexible preferences (Soft Constraints) that define schedule quality. Due to the exponential growth of potential combinations, manual scheduling is mathematically impractical for large departments, necessitating advanced algorithmic frameworks to guarantee a valid and optimized solution (Barták et al., 2010).

## 2.1 Theoretical Framework: Curriculum-Based Scheduling

The academic problem addressed in this project falls under the specific sub-domain of **Curriculum-Based** timetabling. While standard "Post-Enrollment" models attempt to resolve conflicts for every individual student based on specific registration data, Curriculum-Based models assume that students follow a published "recommended curriculum" or pathway.

Although Bonutti et al. (2012) primarily defined the standard for *Course Timetabling* (CB-CTT), their theoretical framework regarding conflict definition is directly applicable to our *Examination* problem. In this model, two events are considered to be in conflict if they belong to the same recommended semester or year, rather than relying on individual student data. This reduction in problem space allows for more robust optimization of the "Hard Constraints" that guarantee the feasibility of the standard academic path.

## 2.2 Theoretical Framework: Constraint Satisfaction and Classification

Mathematically, the examination timetabling problem is modeled as a **Constraint Satisfaction Problem (CSP)**. A *constraint satisfaction problem* consists of:

- a set of variables  $X$  (exams).
- a set of domains  $D$  (the time slots and rooms) that can be assigned to each variable.
- a set of constraints  $C$  that restrict the allowable combinations of assignments (Barták et al., 2020).

Solving a CSP involves finding a state where every variable in  $X$  is assigned a value from  $D$  such that all constraints in  $C$  are satisfied. In the context of the UETP, the complexity stems from the fact that the set  $C$  is not monolithic. Instead, the literature emphasizes a rigorous separation of constraints into a hierarchy: satisfying **Hard Constraints** determines *feasibility*, while optimizing **Soft Constraints** determines *quality* (Burke & Petrovic, 2002).

To solve these NP-hard problems, researchers often utilize techniques like **Integer Linear Programming (ILP)** or **Constraint Programming (CP)**. These methods model binary "yes/no" decisions—such as whether a specific exam is assigned to a specific time slot—to strictly enforce these logical rules (Aslan & Kapanoglu, 2017).

### 2.2.1 Hard Constraints (Feasibility)

These are the inviolable rules that the system must satisfy to produce a valid schedule. The literature supports several critical hard constraints essential for academic logistics:

- **Gap Constraints:** A mandatory gap of more than three days between exams within the same recommended curriculum ensures students have adequate recovery time. This is a variation of the "period-spread" constraint discussed in standard benchmarks.
- **Prerequisite Dependencies:** A foundational course (e.g., *Algorithms 1*) and its successor (*Algorithms 2*) cannot occur on the same day. This prevents "logical

"sequencing" conflicts for students retaking courses, a constraint type formally modeled in Integer Linear Programming (ILP) approaches (Güler et al., 2021).

- **Calendar and Resource Restrictions:** The absolute prohibition of exams on holidays and the limitation of "One Exam per Department on Fridays" act as "masking constraints," effectively removing specific slots from the available search space before optimization begins.

## 2.2.2 Soft Constraints (Optimization Quality)

Once feasibility is achieved, the quality of the schedule is measured by how well it satisfies flexible preferences.

- **Faculty Workload Balancing:** Faculty constraints, such as a minimum gap between invigilation duties (e.g., >3 days), are often treated as soft constraints. *Elen* (2022) notes that while lecturer constraints are critical, treating them as flexible goals rather than rigid rules prevents the system from becoming "over-constrained" and unsolvable.
- **Special Course Handling:** Dedicating specific days to "High-Failure Rate" courses is a heuristic strategy intended to maximize student success rates, prioritizing these courses in the algorithm's objective function.

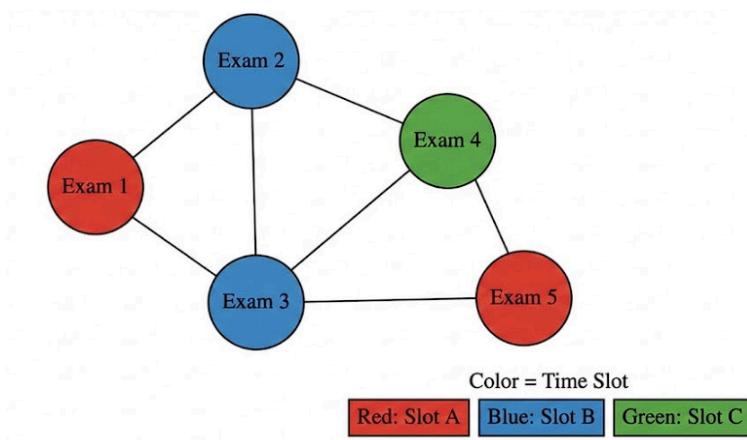
## 2.3 Comparative Analysis of Algorithmic Approaches

Solving the UETP generally falls into three algorithmic categories, each with distinct advantages and disadvantages suitable for different institutional needs.

### 2.3.1 Heuristics and Graph Coloring

Early approaches utilized graph coloring heuristics, where exams are vertices and conflicts are edges (see Fig.1). The goal is to assign "colors" (time slots) such that no two connected vertices share the same color (Burke & Petrovic, 2002).

- **Advantages:** These methods are computationally inexpensive and can generate a result very quickly.
- **Disadvantages:** They are often "greedy" and prone to getting stuck in local optima, meaning they satisfy Hard Constraints but fail to optimize Soft Constraints effectively (*Elen*, 2022).

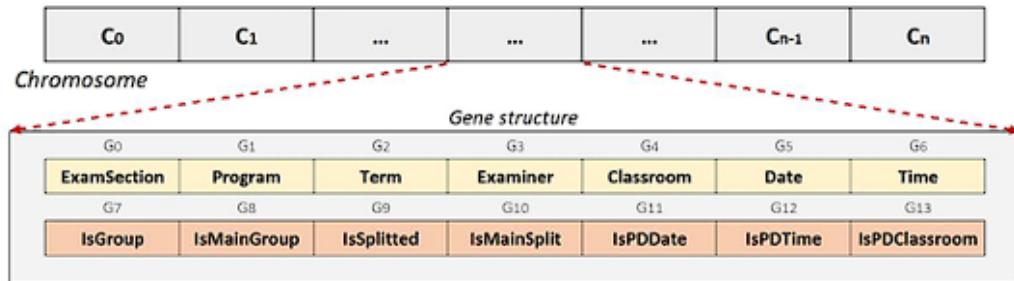


*Figure 1: Graph coloring model where vertices represent exams and edges represent conflicts.*

### 2.3.2 Meta-heuristics (Genetic Algorithms)

Meta-heuristics such as Genetic Algorithms (GA), mimic natural evolution by generating a population of schedules and iteratively improving them through crossover and mutation (Fig. 2).

- **Advantages:** They are excellent at navigating vast search spaces and optimizing quality (Soft Constraints) once a feasible solution is found (Pillay & Banzhaf, 2010).
- **Disadvantages:** They do not guarantee finding a feasible solution (one that breaks zero rules) in a fixed time and they require complex parameter tuning (mutation rates, population size) (Elen, 2022).



*Figure 2: Chromosome encoding used in Genetic Algorithms to represent an exam schedule  
(Adapted from Elen, 2022).*

### 2.3.3 Exact Methods and Constraint Programming (CP)

Exact methods, such as Constraint Programming (CP), model the problem as a set of logical variables and constraints (Fig. 3).

- **Advantages:** Unlike meta-heuristics, CP is designed to prove feasibility. It can guarantee that if a valid schedule exists, it will be found, making it ideal for problems with strict Hard Constraints like prerequisite spacing (Güler et al., 2021).
- **Disadvantages:** These methods can suffer from scalability issues on extremely large datasets (NP-hard) though modern solvers like Google OR-Tools have significantly mitigated this risk (Barták et al., 2020).

```
Recursive BT(free-variables, instantiation, domains)
  if free-variables =  $\emptyset$  then return instantiation
   $x \leftarrow \text{select-one-variable}(\text{free-variables})$ 
   $D_x \leftarrow \text{get-domain}(x, \text{domains})$ 
  while  $D_x \neq \emptyset$  do
     $a \leftarrow \text{select-one-value}(D_x)$ 
    if consistent(instantiation  $\cup$   $(x, a)$ ) then
       $\text{solution} \leftarrow \text{BT}(\text{free-variables} \setminus \{x\}, \text{instantiation} \cup (x, a), \text{domains})$ 
      if solution  $\neq \emptyset$  then return solution
  return  $\emptyset$ 
```

Figure 3: Backtracking Search (Adapted from Barták et al., 2004).

## 2.4 Conclusion: Justification for Selected Approach

Based on the comparative analysis of algorithmic approaches, we decided to utilize an **Exact Method (Constraint Programming)** rather than Heuristics or Genetic Algorithms.

While the literature suggests that Hybrid approaches are necessary for massive datasets to manage scalability, the specific requirements of the Software Engineering Department (approx. 50 courses) fall well within the operational capabilities of modern CP solvers like Google OR-Tools.

- **Handling Hard Constraints:** As noted in Section 2.4.3, CP provides a mathematical guarantee of feasibility, which is critical for the "Hard Constraints" defined by the department (e.g., no double-booking faculty)
- **Optimization capabilities:** Unlike greedy heuristics which get stuck in local optima, a CP solver can search the entire solution space to optimize "Soft Constraints" (student load balancing) without needing a separate repair stage.

Therefore, this project adopts a **Pure Constraint Programming architecture**, leveraging the "Search and Bound" capabilities of the CP-SAT solver to ensure both schedule validity and quality.

### **3. Direct User Interaction (Interviews and Observation)**

The most crucial step in the process was direct engagement with the key stakeholder, Ora, the Head of Department Assistant responsible for scheduling.

We conducted detailed interviews with Ora to understand the existing problems, pain points, and overall goals for the automated system.

To capture the existing manual heuristics and workflow, we scheduled sessions to observe the entire scheduling process, from start to finish. Ora demonstrated her current methodology, which uses an Excel-based system (Fig. 4) and involves several manual steps:

לוח מבחני סוף סטטוסר א' / תשפ"ו - תוכנה													
שנה ג' / פברואר 2020				שנה ג' / פברואר 2020				שנה א' / 110/230					
ספ"י 1 ספ"ר		ספ"י 2 ספ"ר		ספ"י 3 ספ"ר		ספ"י 4 ספ"ר		ספ"י 5 ספ"ר		ספ"י 6 ספ"ר			
410/530	שנה ג' / פברואר 2020	310/430	שנה ג' / פברואר 2020	2310620	ספ"י 5 אביב	2410620	ספ"י 4 אביב	2510620	ספ"י 3 אביב	2610620	ספ"י 2 אביב	2710620	ספ"י 1 אביב
2210600	ספ"י 8 אביב	2310600	ספ"י 7 אביב	2410600	ספ"י 6 אביב	2510600	ספ"י 5 אביב	2610600	ספ"י 4 אביב	2710600	ספ"י 3 אביב	2810600	ספ"י 2 אביב
8 קרטון	שם קרטון	מספר	שם קרטון	מספר	שם קרטון	מספר	שם קרטון	מספר	שם קרטון	מספר	שם קרטון	מספר	שם קרטון
שבט													
מצאות אבטחה מודע													
מצאות אבטחה נזק													
סוף סטטוסר א'													
מצגות טריזיטים													
61999	מוגוז פורייזטים	61998										11064	אנגליה מתקדמים א'
שבט													
מג'וריה רוחש													
61757												61774	אנגליה רוחש
מג'וריה רעליה													
61752												11066	דנמרק מ'
דנמרק מ'													
11004												30/01/2026	שוודיה
שוודיה													
31/01/2026												29/01/2026	בדויניה
01/02/2026												02/02/2026	שוודיה
02/02/2026												03/02/2026	בדויניה
03/02/2026												04/02/2026	שוודיה
04/02/2026												05/02/2026	בדויניה
05/02/2026												06/02/2026	שוודיה
06/02/2026												07/02/2026	שבט
שבט													
61965	כנית של דנרו רוחשות											61739	מבנה צוותים
מבנה צוותים													
61765												61738	מבנה 1
מבנה 1													
61755	סודן נזק											61741	סודן נזק
סודן נזק													
61775	לבוניה נזק											61778	לבוניה נזק
לבוניה נזק													
שבט													
61959	אנגליה נומרת											61750	מבנה צוותים
מבנה צוותים													
מבנה צוותים													
61759												61740	STRUCTURE
STRUCTURE													
61740												09/02/2026	שוודיה
09/02/2026												10/02/2026	בדויניה
10/02/2026												11/02/2026	שוודיה
11/02/2026												12/02/2026	בדויניה
12/02/2026												13/02/2026	שוודיה
13/02/2026												14/02/2026	שבט

*Figure 4: Example of Schedule*

- **Calendar Exclusion:** Marking off holidays and fast days from the schedule.

אוון לקליטם בחרנות - פורום	שני	02/03/2026
אוון לקליטם בחרנות - פורום	שלישי	03/03/2026

- **Sequencing and Prioritization:** Initial scheduling based on internal knowledge, such as ensuring wide spacing for exams with high failure rates (an implicit soft constraint).
  - **Faculty Constraints:** Manually ensuring a gap for each lecturer.
  - **Post-Processing:** Entering the final, approved schedule into the Gilboa system one by one.

During the observation, follow-up questions were asked to clarify specific decision-making processes, particularly regarding the trade-offs involved in scheduling conflicts and the priority given to Staff members' constraints over others.

- Does the scheduling strictly follow the recommended academic track?
  - What is your preferred format for viewing the generated schedule?

- How do you currently manage the scheduling process? (Request for a live demonstration)
- Which constraints are prioritized during the initial phase (e.g., minimum 2-semester gap)?
- How is information regarding faculty availability and preferred dates reported to you?
- When and how are exam dates for cross-departmental courses (e.g., English, Hebrew) received and integrated?

### 3.1 Document Analysis

The formal framework of the project was derived from analyzing the provided requirements document (the "Ora Requirements" document, Fig 5), which defined all the essential **hard constraints** and entities.

**Defining Constraints:** The document analysis established the rigid scheduling rules:

- Duration of exam periods (4 weeks for Moed A and 2 weeks for Moed B).
- Maximum number of exams per week (3).
- Faculty categorization (Staff vs. Adjunct) and the specific requirement to adhere strictly to Staff member constraints.
- Logistical rules (e.g., maximum one Friday exam per department).
- Handling of cross-departmental exams (e.g., Arabic, English, Calculus) which must be held simultaneously.

#### General:

- The college's lecturers are divided into faculty members and external lecturer; this is not the same – they must be distinguished
- Only the constraints of faculty members should be taken into account
- Faculty Member:
  - Faculty members have different ranks: teacher, lecturer, professor

- Each department is allowed one exam on Friday
- There are lateral exams (Arabic, English, Hidya) that are held in all departments
- It is forbidden to take 2 exams per lecturer in the same week, unless he or she agrees

#### Course Constraints:

- Duration of the test
- Number of students in the course
- The exams are per semester, so there is no problem with a clash with an exam from another semester

#### Constraints of the Information System

##### Specialization:

- Is it unique to the program
- Is the 2 programs common
- Compatibility between the two systems must be ensured => must be synchronized with an information systems specialization

##### Semester Constraints:

- Winter/Summer

#### The system that will be built:

- Will offer test placements
- Placement will happen automatically
- Allow further scrambling after entering a certain parameter

*Figure 5: Ora's Requirements*

**Defining Entities:** The analysis formalized the required data entities (Fig 6), including Course details (duration, student count, type) and the need for synchronization between the Software Engineering and Information Systems programs.

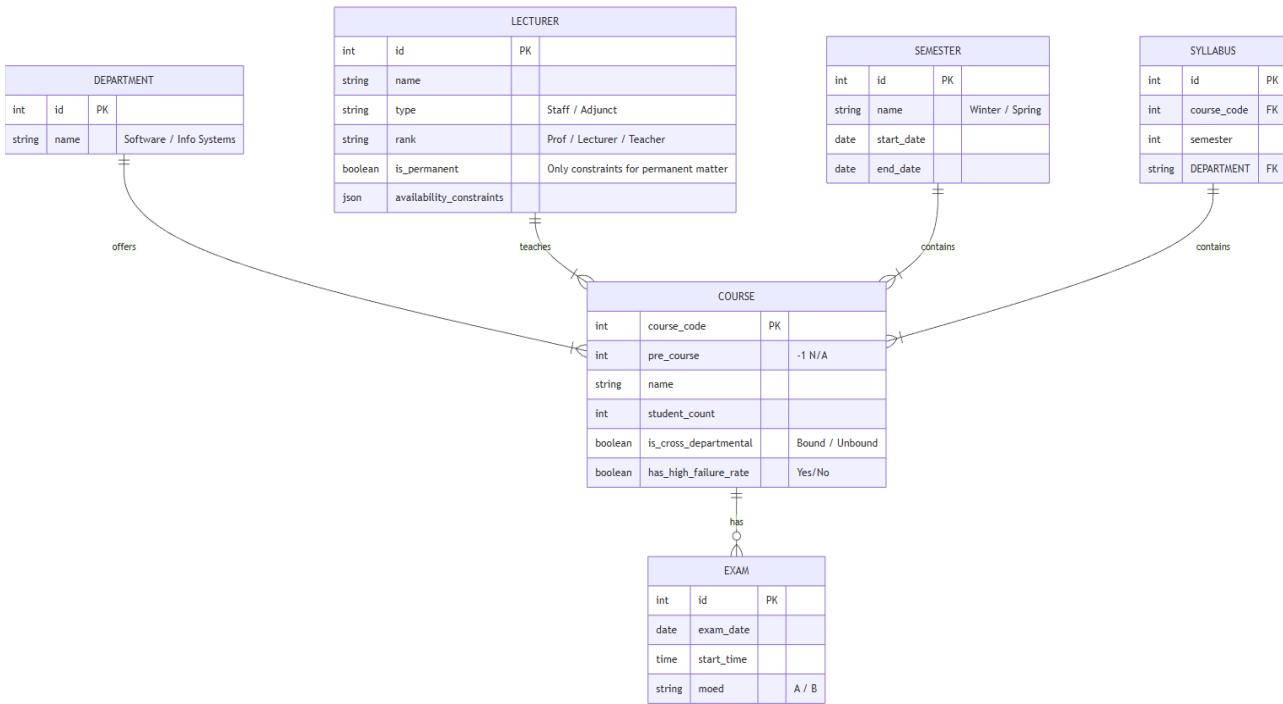


Figure 6: Entity-Relationship Diagram

This combined approach ensures that the system is not only functionally compliant with all written rules but is also practically usable and effective for the end-user's day-to-day workflow.

## 4. Development Process

The development of the Computerized Examination Scheduling System (CES) follows a structured approach that prioritizes the complex logistical constraints of the department while ensuring a flexible user experience. We employ a phased methodology, transitioning from human-centered requirements gathering to a robust mathematical optimization architecture.

### 4.1 The Process

The development process comprises all four phases of the UCD approach: (1) understanding the context, (2) specifying user requirements, (3) designing solutions, and (4) evaluating against requirements (Shneiderman & Plaisant, 2010). Phase 4 is explained in more detail in section 7.

#### 4.1.1 Understanding the Context

To foster a deep understanding of the problem domain, we analyzed the current manual scheduling process, which is characterized by disorganized data and heavy reliance on fragmented spreadsheets.

- **Stakeholder Interaction:** The most crucial step was direct engagement with **Ora**, the Head of Department Assistant responsible for scheduling. We conducted detailed interviews to understand pain points, such as the risk of scheduling errors during multi-faith fast days.
- **Structured Observation:** We observed the existing manual methodology, which involves manual calendar exclusion for holidays, sequencing based on internal knowledge (such as spacing high-failure rate courses), and manual entry into the **Gilboa** system.
- **Document Analysis:** The formal framework was derived from the "**Ora Requirements**" document, which established the rigid boundaries of the academic calendar (4-week Moed A, 2-week Moed B) and mandatory student load limits (max 3 exams per week).

#### 4.1.2 Specifying User Requirements

Based on stakeholder interaction and document analysis, we identified the following functional and non-functional requirements.

##### Functional Requirements (FR)

ID	Requirement	Category
FR1	The system shall allow the Administrator to define and mark specific dates as "blocked" (e.g., holidays, fast days) to prevent exam scheduling on these days.	Configuration & Input
FR2	The system shall provide an interface to classify faculty members by rank and toggle constraint applicability (e.g., enable/disable constraints for external lecturers).	Configuration & Input
FR3	The system shall execute a scheduling algorithm to generate a complete exam timetable for Moed A and Moed B.	Scheduling Algorithm

<b>FR4</b>	During schedule generation, the system shall validate that no student group exceeds the configurable limit of exams per week (default: 3).	Validation Rules
<b>FR5</b>	The system shall verify that no lecturer is assigned to more than one exam per week and alert the user if a conflict is detected without a manual override.	Validation Rules
<b>FR6</b>	The system shall identify courses flagged as "Shared" or "Cross-Departmental" and force simultaneous scheduling for these exams across all relevant department schedules.	Scheduling Algorithm
<b>FR7</b>	Re-shuffle Mechanism: The system shall allow the user to manually lock specific exam slots (fix a date/time for a course) and re-execute the scheduling algorithm for the remaining unscheduled exams.	Flexibility & Optimization

### Non-Functional Requirements (NFR)

ID	Requirement	Category
NFR1	<b>Execution Time:</b> The automatic algorithm shall be required to produce a Valid Schedule within <b>up to 60 seconds</b> from activation.	Performance
NFR2	<b>Usability:</b> The User Interface shall be intuitive and tailored for a non-technical user (the Administrative Assistant), allowing for a clear presentation of the schedule and potential conflicts.	User Interface

NFR3	<b>Security and Privacy:</b> Access to the system shall be granted only through user authentication, and sensitive data (such as faculty details) shall be stored securely.	Security
NFR4	<b>Maintainability:</b> The system shall be designed with modularity to allow for easy updates to scheduling rules and the addition of new constraints in the future.	Code Quality

#### 4.1.3 Designing Solutions - Prototype

The system features three primary interconnected modules developed to simulate the administrative workflow:

- **Constraints & Settings View:** Allows the administrator to set the Moed periods, toggle holiday avoidance, and define student load (Figs 7,8,9).

The screenshot shows the 'University Examination Scheduling' administrative portal. The top navigation bar includes 'Import & Validation', 'Constraints', 'Calendar', 'Conflict View', 'Exam Details', and 'Settings'. The main content area is titled 'Scheduling Constraints' and describes how to configure rules and restrictions for automatic exam scheduling. It lists several constraints under 'Calendar Rules': 'Avoid Holidays' (Prevent scheduling exams on public holidays and university breaks), 'Avoid Weekends' (Only schedule exams on weekdays), 'Minimum Gap Between Exams' (Minimum days between exams for the same student group, set to 2 days), and 'Student Workload': 'Max 3 Exams Per Week' (Limit the number of exams per student in a single week) and 'Max Exams Per Day' (Maximum number of exams a student can have in one day, set to 1 exam). Each constraint has a toggle switch to enable or disable it.

Figure 7: Constraint Alignment

**Lecturer Availability**

**Lecturer Minimum Gap**  
Minimum hours between invigilating duties for the same lecturer  hours

**Max Invigilation Per Day**  
Maximum exams a lecturer can invigilate in one day  exams

**Time Slot Preferences**

**Prefer Morning Slots**  
Prioritize scheduling exams in morning hours (9:00 AM - 12:00 PM)

**Buffer Time Between Exams**  
Time gap between consecutive exams in the same room  min

**⚠ Strict Constraints May Affect Scheduling**  
Enabling multiple strict constraints may make it difficult to find a valid schedule. Consider relaxing some rules if scheduling fails.

Last saved: 2 hours ago Reset to Defaults Save Configuration

Figure 8: Lecturer Alignment

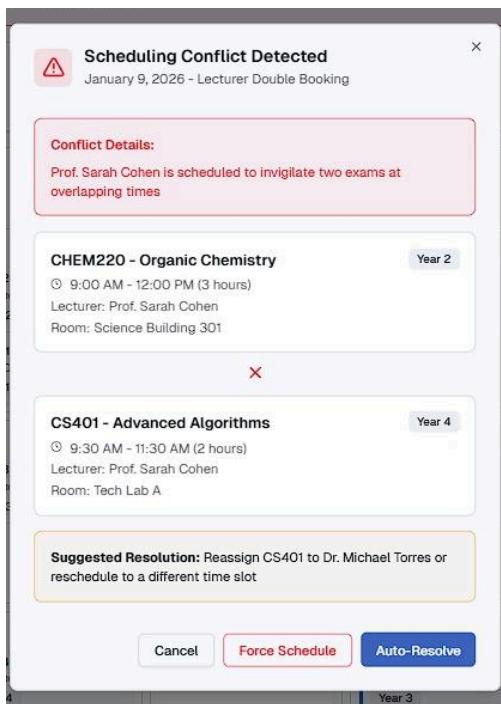


Figure 9: Conflict Preview

- **Data Management Portal:** Supports bulk uploads of teacher constraints and course information via CSV or Excel (Fig 10).

The screenshot shows the 'University Examination Scheduling' administrative portal. At the top, there's a header with a logo, the portal name, and a 'Settings' button. Below the header, a navigation bar includes links for 'Import & Validation', 'Constraints', 'Calendar', 'Conflict View', and 'Exam Details'. A prominent green success message 'File Upload Successful' is displayed, along with a timestamp: '2020-01-01 10:00:00 AM'. Below this, a summary row shows 'Total Rows: 234', 'Valid: 228', and 'Warnings: 6'. A 'Download Report' button is also present.

The main content area is titled 'Data Validation Warnings' and contains a table with columns: Row, Course, Issue Description, Severity, and Action. The table lists several errors and warnings, such as 'Missing Student Count' for CS301 and 'Invalid Date Format' for MATH201. A total of 6 issues are indicated at the top right of the table.

At the bottom of the warning section, there are buttons for 'Re-upload File' and 'Proceed to Scheduling (3 errors)'. A note at the bottom left says 'Fix all errors before proceeding to scheduling'.

*Figure 10: File Upload of constraints and preview of warnings.*

- **The Main Scheduler:** A dynamic interface where scheduled and unscheduled exams are presented alongside a monthly calendar, supporting the manual **Re-shuffle** capability. (Fig 11)

This screenshot shows the 'Main Month Schedule preview' interface. It features a monthly calendar for January 2020, with each day containing a grid of exam slots. Each slot displays course details like 'CS301', 'Year 3', and times. To the right of the calendar is a sidebar titled 'Unscheduled Courses' with a drag-and-drop area. The sidebar lists five courses with their respective details:

- ART301 (Year 3): 30 students, 3h duration
- MUS201 (Year 2): 32 students, 2h duration
- HIS401 (Year 4): 28 students, 3h duration
- GEO101 (Year 1): 67 students, 2h duration

*Figure 11: Main Month Schedule preview*

## 4.2 Architecture

### 4.2.1 Core Technologies and Tools

The choice of technologies was driven by the need for robust mathematical optimization and rapid web deployment. These technologies power the base to our system (Fig 12).

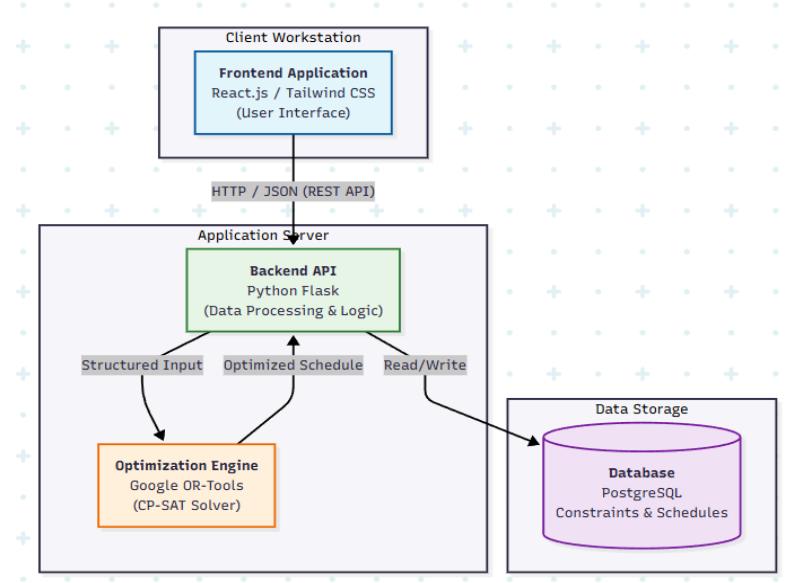


Figure 12: Technology Diagram

Technology	Role in Project	Justification
Python <sup>1</sup>	Primary Programming Language	Python offers extensive libraries for data manipulation and optimization, making it the industry standard for operations research tasks.
Google OR-Tools <sup>2</sup>	Optimization Solver	An open-source software suite for optimization. Specifically, its <b>CP-SAT Solver</b> (Constraint Programming) is ideal for scheduling problems with complex, discrete constraints like ours (e.g., "no two exams for the same lecturer").

<b>Pandas<sup>3</sup></b>	Data Processing	Used for efficient parsing, cleaning, and structuring of the input data (Excel files) before feeding it into the optimization model.
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<sup>1</sup> Python Software Foundation. (n.d.). *Welcome to Python.org*. <https://www.python.org/> <sup>2</sup> Google. (n.d.). *OR-Tools | Google Developers*. <https://developers.google.com/optimization> <sup>3</sup> The pandas development team. (n.d.). *pandas documentation*. <https://pandas.pydata.org/>

## Backend Development (Server Side)

The backend serves as the bridge between the user interface and the algorithmic core.

Technology	Role in Project	Justification
<b>Flask (Python)</b>	Web Framework	A lightweight micro-framework that allows for quick setup of API endpoints. It integrates natively with the Python-based optimization core, eliminating the need for complex inter-process communication.
<b>REST API</b>	Communication Protocol	Standard architectural style for communication between the Client and Server, ensuring modularity and scalability.

## Frontend Development (User Interface)

The frontend provides the interactive environment for the Administrative Assistant.

Technology	Role in Project	Justification
<b>React.js</b>	Frontend Framework	A JavaScript library for building user interfaces. Its component-based architecture is perfect for managing

		the dynamic state of the schedule view (e.g., dragging and dropping exams).
<b>Tailwind CSS</b>	Styling Framework	A utility-first CSS framework that allows for rapid UI development with a clean, modern aesthetic, ensuring the system is visually accessible and professional.
<b>Axios</b>	HTTP Client	Used to send asynchronous HTTP requests to REST endpoints and perform CRUD operations (Create, Read, Update, Delete) on the scheduled data.

## Data Management

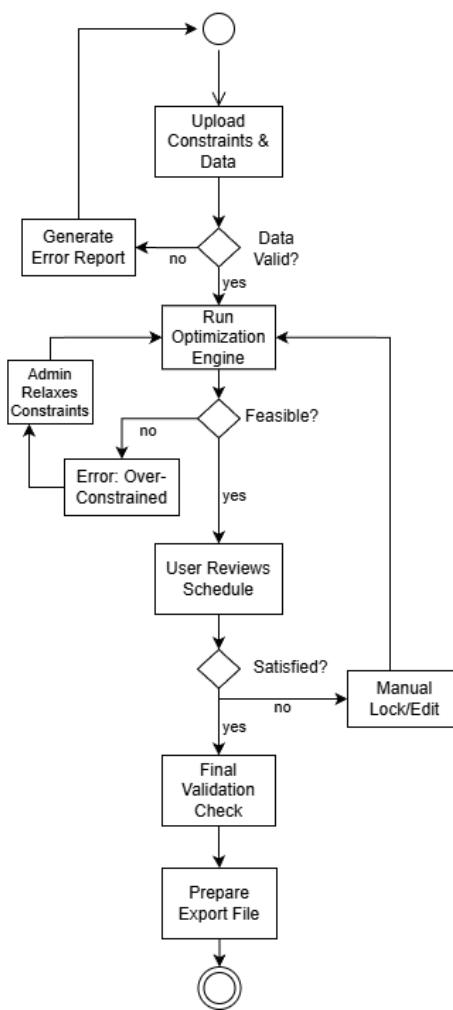
Reliable storage is essential for maintaining course lists, faculty constraints, and generated schedules.

Technology	Role in Project	Justification
<b>PostgreSQL</b>	Database	An advanced, open-source object-relational database system. Its reliability and support for complex queries make it suitable for storing the relational data of the university's entities (Students, Courses, Faculty).
<b>JSON / CSV</b>	Data Interchange Formats	CSV is used for the initial bulk data import (from the department's Excel files), while JSON is used for lightweight data exchange between the Frontend and Backend.

## 5. System Operational Flow

The end-to-end workflow emphasizes **User-Centered Design** (Fig 13), where the algorithm provides an optimal starting point but final authority rests with the user (**Shneiderman & Plaisant ,2010**).

1. **Data Ingestion:** Uploading constraints and raw department data.
2. **Validation:** Checking data validity and generating error reports if inconsistencies are found.
3. **Two-Stage Optimization:**
  - o **Stage 1: Constructive Heuristic** to satisfy all hard constraints.
  - o **Stage 2: CP Optimizer** to refine the schedule based on soft preferences.
4. **User Review & Re-shuffle:** The administrator reviews the schedule. If unsatisfied, a manual re-shuffle allows for locking specific slots and recalculating the remaining assignments.
5. **Final Export:** Once approved, the data is exported in a format compatible with the **Gilboa** system.



*Figure 13: Activity Diagram displaying User Centered Design.*

## 6. Expected Challenges

Based on our initial research and requirements gathering, it is clear that developing the Computerized Examination Scheduling System involves significant technical and logistical hurdles. Transitioning from a manual, experience-based process to a fully automated algorithmic solution presents several key challenges we need to address.

- **Algorithmic Complexity and Performance:** The core problem we are solving is NP-hard, meaning the number of possible schedule combinations is massive due to "combinatorial explosion." A major technical challenge will be implementing an algorithm efficient enough to navigate this huge search space and generate a valid schedule within our 60 second performance requirement.
- **Modeling Implicit Human Knowledge:** During our interviews with the administrator, we learned that many scheduling decisions depend on "implicit heuristics" human intuition that isn't officially written down, such as knowing which difficult courses need extra spacing between exams. Translating this qualitative knowledge into precise mathematical constraints for the engine will be difficult.
- **External Dependencies and Synchronization:** The requirement to synchronize "cross-cutting exams" (like Calculus or English) poses a significant risk. Because these are controlled by external departments, a sudden schedule change on their end could instantly invalidate our entire departmental timetable.
- **Implementing the "Re-shuffle" Capability:** The feature allowing users to manually lock specific slots and re-run the schedule is computationally complex. The challenge is ensuring the algorithm can quickly detect if a user's manual lock creates an impossible scenario for the remaining exams and communicate that clearly to the user.

## 7. Evaluation Plans

### 7.1 Testing Plan

This plan verifies that the Computerized Examination Scheduling System (CES) meets technical specifications and provides real-world utility for the department administrator, addressing the requirements for validation and success criteria.

The testing process is divided into four main phases:

#### Phase 1: Data Import and Integrity Tests

**Goal:** Verify correct parsing and filtering of input data based on departmental logic. This phase confirms that the system accurately parses the uploaded Excel file, correctly classifies faculty (prioritizing permanent staff constraints over external lecturers), filters out elective courses as required, and identifies shared "bound" courses needing synchronization vs. unique "unbound" courses.

## **Phase 2: Hard Constraint Verification (Feasibility)**

**Goal:** Validate strict adherence to the non-negotiable "Iron Rules." Testing ensures the system never violates critical constraints: enforcing a mandatory 4-day gap between a lecturer's exams, honoring specific lecturer blackout dates and all religious holidays, ensuring simultaneous slots for cross-departmental exams, and limiting Fridays to a maximum of one exam per department.

## **Phase 3: Soft Constraints and Optimization Quality**

**Goal:** Verify the system generates a "smart" schedule optimized for student success. This phase assesses the quality of the schedule by verifying that the algorithm maximizes study gaps leading up to identified "high-failure rate" courses, prioritizes buffers between prerequisite and advanced courses, and efficiently schedules non-conflicting unlinked courses in parallel.

## **Phase 4: Performance and Usability Testing**

**Goal:** Ensure the system meets speed requirements and is usable for the administrator. Testing confirms that the system can generate a valid schedule for a standard 50 course dataset within ~60 seconds. It also validates the "Re-Shuffle" capability, ensuring the engine can correctly regenerate the schedule around manually locked slots without breaking hard constraints.

### **7.2 User Evaluation**

The user will evaluate the system by performing a full scheduling workflow using realistic departmental data. Following hands-on usage, the user will complete a **System Usability Scale (SUS)** questionnaire along with several additional qualitative questions to assess usability, clarity, and overall satisfaction with the system (Brooke, 1995).

### **7.3 Key Metrics for Evaluation**

The system's success will be measured against the following quantitative algorithmic goals and qualitative user experience targets for the Department Administrator.

#### **Quantitative Metrics (Algorithmic Performance)**

- **Feasibility Rate:** Achieve **100% compliance** with all "Hard Constraints." Any single violation (e.g., double-booking faculty or scheduling on a Fast Day) renders the schedule invalid, detected by automated validation scripts.
- **Execution Efficiency:** Generate a complete, valid initial schedule for a standard semester (approx. 50 courses) in **≤ 60 seconds**.
- **Soft Constraint Optimization:** Demonstrate improved schedule quality (e.g., better study gaps between exams) compared to historical manual baselines.

- **Re-Shuffle Responsiveness:** Regenerate a valid schedule following a manual user adjustment (e.g., locking a slot) in **≤ 30 seconds**.

#### **Qualitative Metrics (User Experience & Workflow)**

- **Usability Score (SUS):** Achieve a System Usability Scale score **> 80** based on a standard survey completed by the Administrator (Ora) after testing.

## **8. GenAI Usage Discloser**

During the preparation of this work, the authors used Gemini and ChatGPT to enhance language and grammar. After using this service, the authors reviewed and edited the content as needed and took full responsibility for the content of the published article.

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